Golder Associates Inc.
18300 NE Union Hill Road, Suite 200
Redmond, Washington 98052
Telephone: (425) 883 0777
Fax: (425) 882 5498

FINAL

LITTLE BEAR CREEK HYDROGEOLOGIC OVERVIEW

Submitted to:

Jones & Stokes
11820 Northup Way
Bellevue, WA 98005

Submitted by:

Golder Associates Inc.
18300 NE Union Hill Road, Suite 200
Redmond, Washington 98052

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1.0 INTRODUCTION

This report presents an overview of groundwater conditions in the Little Bear Creek sub-basin. It is intended to briefly summarize existing information, depict hydrogeologic conditions, and describe potential groundwater contamination pathways or issues specific to Little Bear Creek.

1.1 Hydrogeological Information Sources

Mapping: Mapping data are available from the following sources:

- US Geological Survey (USGS) 7.5-minute topographic maps;
- USGS surface geological maps for the Bothell (Minard 1985), Kirkland (Minard 1983), Maltby (Minard 1985), and Redmond (Minard and Booth 1988) Quadrangles; and
- Agency GIS coverages, including surface geology; areal extent of geologic units; geological unit top elevations; and groundwater recharge rate.

Regional Hydrogeology: Geological and hydrogeological data are available from a variety of sources. Work completed by Newcomb (1952), Liesch et al. (1963), and Thomas et al (1997) provided detailed characterizations of the geology and the groundwater resources of Snohomish County and northwestern King County. The Cross Valley Water District (CVWD) Wellhead Protection Plan (WHPP) prepared by Golder (2000) also provides a detailed review of the hydrogeology, and included development of a groundwater flow model.

WDOE Well Logs: Hydrogeological data are available from well logs on file at the Washington State Department of Ecology (WDOE) in Bellevue, WA. A number of these well logs were reviewed and used to create a well database for the CVWD WHPP containing information on location, ownership, water levels, geologic stratigraphy and, when available, the results of well testing. A number of these wells were used to develop cross sections shown in Appendix A.

1.2 Sub-Basin Description

The Little Bear Creek subbasin encompasses approximately 8,550 acres and is bounded by low topographic boundaries with the North Creek sub-basin to the west, and the Bear Creek, Cathcart and marshland sub-basins to the east.

2.0 LAND USE EFFECTS ON GROUNDWATER

2.1 General Land Use Concerns

General land use concerns with regard to groundwater effects are summarized below:

- **Impervious surfaces** such as roads, parking lots and buildings can physically block recharge to groundwater if runoff from these surfaces is not discharged to stormwater infiltration facilities. Impervious surfaces and infiltration of stormwater is a concern in Little Bear Creek, particularly in the Maltby/Clearview industrial areas.
- **Stormwater infiltration** into groundwater has the potential to degrade groundwater quality, particularly in areas of commercial and industrial land use. Roadways, parking areas and residential developments contribute heavy metals and petroleum hydrocarbons that originate primarily from vehicles. Industrial and commercial areas can discharge similar constituents. Groundwater contamination from stormwater infiltration is a concern in Little Bear Creek. However, many of these constituents are attenuated (absorbed) by soil particles as they migrate to the groundwater, and Best Management Practices (BMPs), such as the use of grass biofilters, are effective at removal.
- **Consumptive use** of groundwater can have an impact on stream baseflow and has the potential to lower water levels within the aquifer if consumptive use exceeds recharge. Of particular concern in some areas is the combined effect of domestic or small municipal groundwater withdrawals combined with centralized sewer services. In this situation, consumptive use of groundwater is magnified because there is no return of the pumped groundwater via on-site wastewater treatment systems (septic tanks). The western portion of Little Bear Creek is not served currently by either the Cross Valley or Alderwood water districts, but would be required to be sewered per county policy. Therefore, consumptive use could be an issue in Little Bear Creek.
- **Nitrogen loading** is a concern because it is associated with many types of groundwater contamination and is relatively mobile in groundwater. It is therefore a good general indicator of groundwater quality. Nitrogen is present in fertilizers and sanitary wastewater discharges (septic drainfields), and can be an indicator of groundwater quality effects from residential development. Nitrogen loading from septic drainfields is not a significant issue in proposed urban growth areas in Little Bear Creek since this land use would require sewers and there would be a reduction in on-site wastewater disposal.
- **Pesticide loading** typically occurs as a result of pesticide use in residential areas, along transportation corridors, and along transmission line and railway line rights-of-way. The term pesticide is inclusive of a suite of related products including insecticides, herbicides and fungicides. Most are toxic to humans and animals in small quantities. Pesticide loading is potentially a concern in Little Bear Creek.
- **Corridor spills** associated with new pipelines or transportation alignments, such as Highway 9 and State Routes 524 and 522, are a concern in the area. The contaminant of most concern (in terms of human toxicity and mobility and persistence in the environment) associated with transportation corridor spills is likely to be methyl tertiary butyl ether (MTBE), a gasoline additive. The behavior of MTBE in the environment is considerably more complex and long-lived than other gasoline components. It is soluble in water and does not significantly sorb to aquifer materials.

2.2 Current and Proposed Land Use

The primary area associated with the County Council FEIS Map List that would experience increased zoning density compared to current allowable land use is in the northwestern quadrant of the Little Bear Creek sub-basin (see Figure 6). Other smaller areas are present to the south, but are not shown on Figure 6. Figure 1 shows all land use changes associated with the FEIS Map List. The table below summarizes land use under the current (no action) land use and the proposed (FEIS) land use.

Land use Code	Description	Current	Proposed
20	Incorporated City	-	2.3
206	Rural Residential (1 DU/5 Acres Basic)	7,014.4	6,123.2
254	Urban Low Density Residential (4 - 6 DU/Acre)	953.6	1,429.9
255	Urban Medium Density Residential (6 - 12 DU/Acre)	-	221.8
256	Urban High Density Residential (12 to 24 DU/Acre)	-	15.3
302	Public/Institutional Use	32.0	87.0
352	Clearview Rural Commercial	57.6	58.9
402	Urban Industrial	492.8	612.7
504	Centers-Urban Village	-	3.9

2.3 FEIS Screening Results

In the screening analysis, (Golder, 2005) conducted for the Comprehensive Plan Update the groundwater analysis consisted of a comparison at a sub-basin scale between the distribution of land use codes under the existing condition (Alternative 1 of the DEIS) and other alternative land use patterns (Alternatives 2 and 3 of the DEIS and the recommendation of the FEIS). A relationship between land use type and three groundwater indicators was used to calculate the relative magnitude of groundwater effect between current land use distribution (Alternative 1) and other alternatives, for each sub-basin in Snohomish County. The three groundwater indicators used in the analysis were:

- Groundwater recharge;
- Consumptive use of groundwater; and
- Nitrate loading.

The relationship between land use code and groundwater was established through land use factors developed previously in the Groundwater Management Plan. No attempt was made to adjust land use codes or land use factors within any individual sub-basin. This was necessary to meet the constraints of a county-wide planning level analysis and to allow for a consistent comparison between sub-basins.

The screening results indicated the following potential groundwater effects in Little Bear Creek from the land use proposed in the FEIS (County Council Map List):

- Effective impervious area would increase from 1,059 acres to 1,416 acres, resulting in an estimated recharge reduction of 550 acre feet (from 11,567 acre-feet to 11,106 acre feet). Consumptive use of groundwater would increase from 141 acre-feet to 161 acre-feet. The increase in impervious area combined with the increase in consumptive use of groundwater. This is equivalent to a recharge reduction of 570 acre-feet. Relative to current allowable land-use and to other sub-basins, the FEIS alternative produced an effect in Little Bear Creek that was higher than most other sub-basins in the County.
- Nitrate loads would decrease from 15,065 kg/yr to 14,988 kg/year. This is primarily due to the requirement that all new urban development in the basin would be served by sewer, thus reducing nitrate loading from on-site wastewater disposal systems.

3.0 HYDROGEOLOGY

The conceptual hydrogeologeologic model of the sub-basin is based primarily on information published by the United States Geologic Survey (USGS) and on well logs filed at the Department of Ecology's (DOE)

3.1 Surficial Geology

Figure 2 shows the surface geology of the project area. Seven principal hydrogeologic units (described below) are present within the project area. Hydrogeologic units can be characterized as either an aquifer or as a confining layer. An aquifer is a saturated permeable geologic unit that is capable of transmitting a usable quantity of water. A confining layer is a geologic unit that restricts the movement of groundwater.

1. **Alluvium (Qal)** is the youngest hydrogeologic unit. This unit is present along several stream channels and typically consists of sand and gravel with some finer-grained materials including organic deposits. The alluvium does not represent a viable aquifer because it covers a relatively small area and is often unsaturated. In other parts of Snohomish County the alluvium is an aquifer, such as in the Snohomish River Valley.
2. **Vashon recessional outwash (Qvr)** is the second hydrogeologic unit in the vertical sequence. This unit was deposited by streams emanating from the melting and receding Vashon Glacier approximately 13,000 to 15,000 years ago. It is comprised of sediments ranging from fine-grained silt to coarse-grained sand and gravel. In the project area, it mostly occurs in stream drainages. The potential of this unit as an aquifer is limited by a relatively thin saturated thickness.
3. **Vashon till (Qvt)** is a confining layer that occurs extensively in the project area and ranges in thickness from a few feet thick to up to over 150 feet thick. The greatest thicknesses of till occur over higher ground such as the Mount Forest area. Much of the land surface consists of Vashon till. However, it is absent along the portions of the Little Bear Creek Valley, where it has been eroded away. Commonly referred to as hardpan, till is a dense, poorly sorted mixture of clay to gravel sized particles deposited directly from a continental glacier and consequently compacted by the thick ice pack. The description of the till in area well logs is quite variable. It is variously described on well logs as a "clay hardpan", "sandy clay", "dark gray sandstone clay", "gray claystone", "sandy gravely till", "gray cemented sand and gravel", or "gravely, sandy clay and silt".
4. **Vashon advance outwash (Qva)** is present below the till and locally at land surface. This unit was deposited by meltwater streams emanating from the advancing continental glacier. The Vashon advance outwash consists of a number of layers ranging in texture from sandy silt to sandy gravel. The coarse-grained layers consisting of sand and gravel tend to be located within the lower portions of the unit and are tapped by productive water wells. The Vashon advance outwash is a significant aquifer. This unit is described within the logs as a "water bearing sand and gravel", "gravel with sand and water", "blue water bearing sand and gravel", "brown sand", "gray sand" and "gravel".

5. **Transitional beds (Qtb)** are a confining unit that underlies the Vashon advance outwash. Deposition of this unit is believed to occur during an inter-glacial period when continental glaciers had retreated from the Puget Sound area. Clay and silt strata are characteristic of the transitional beds.
6. **Undifferentiated sediments (Qu)** occur below the transitional beds. This unit has been classified as an aquifer unit by the USGS (Thomas et al., 1996). It is not known if this unit is of aquifer quality in the project area.
7. **Bedrock (Tb)** consists of a variety of sedimentary rocks, which are present in outcrop along the northeast portion of the project area.

3.2 Principal Aquifer

The principal aquifer in the area is the Advance Outwash (Qva). It is often called the Cross Valley Aquifer, and is the primary water supply for the Cross Valley Water District (CVWD). The aquifer is located between 20 to 100 feet below ground surface, and daylights (is exposed at the ground surface) along the Little Bear Creek, Paradise Valley and Evans Creek drainages.

Figure 3 shows the estimated top elevation of the top of the Vashon advance outwash (Qva) aquifer in the project area. This map was developed by Golder previously for the CVWD WHPP (Golder, 2000). The top elevation represents the top of the aquifer, where the Vashon advance outwash is fully saturated. Over much of the area the aquifer is unconfined and therefore the top of the aquifer is determined by the water table, which occurs at an elevation below the top of the Vashon advance outwash. The top elevation ranges from about 40 feet to 550 feet above mean sea level and generally follows the surface topography. It is highest in the plateau areas and lowest in the stream valleys where it has been eroded.

Of particular note is the presence of advance outwash (Qva) at the ground surfaces in the northwest portion of the sub-basin, and along Little Bear Creek. Portions of the proposed up zoning in the FEIS Council Map List are located in areas where advance outwash (Qva) is mapped at the ground surface. Areas where the Qva is exposed at ground surface are more susceptible to contamination than areas where there is a protective glacial till cap.

3.3 Hydraulic Properties

The USGS (Thomas et al., 1996) presented hydraulic properties for the Vashon advance outwash and other hydrogeologic units. The USGS determined hydraulic conductivity based on the specific capacity from water wells in the area. As noted by the USGS (Thomas et al., 1997), the estimated hydraulic conductivity for the low permeability units (Qvt, Qtb, Tb) are biased toward higher values, as wells were only completed in the most permeable materials encountered. The USGS estimated the following hydraulic conductivity values:

		Hydraulic Conductivity (ft/day)		
Hydrogeologic Unit	*Number of Wells*	*Min.*	*Median*	*Max.*
Alluvium (Qal)	30	3.6	88	3,200
Vashon recessional outwash (Qvr)	48	0.08	180	1,800
Vashon till (Qvt)	60	0.04	53	1,000
Vashon advance outwash (Qva)*	171	3.8	86	3056
Transitional beds (Qtb)	16	0.025	20	280
Undifferentiated deposits (Qu)	54	0.22	31	1,800
Tertiary bedrock (Tb)	47	0.0023	0.82	310

* Vashon advance outwash data is a compilation of upper and lower advance outwash and includes analyses of pumping tests in municipal production wells.

The hydraulic conductivity data presented above all pertain to the horizontal direction. The hydraulic conductivity, however, has a different value for groundwater flow in the vertical direction. In horizontally layered materials, the vertical hydraulic conductivity will be less than that for the horizontal direction. Vertical hydraulic conductivity may range from 1/10 to 1/1,000 of the horizontal value. In general, a higher horizontal hydraulic conductivity will correspond to a higher vertical hydraulic conductivity that, in some cases, structural or depositional anomalies (cracks, fissures, erosional features) can result in higher vertical hydraulic conductivity than would be predicted based on a percentage of the horizontal hydraulic conductivity. No measurements of vertical hydraulic conductivity were identified in the project area.

3.4 Groundwater Recharge/Discharge

Groundwater discharge to Little Bear Creek was estimated based on streamflow data from USGS station 12125500 located on (Little) Bear Creek in Woodinville, WA. Streamflow data were collected at this station from 1945 to 1969. A hydrograph of the average monthly streamflow during the period of record is shown on Figure 4. The average annual flow at this station (drainage area of 15.3 mi^2) was 23.4 cubic feet per second (23.4 cfs). A conservative (low) estimate of the average annual groundwater baseflow discharge to (Little) Bear Creek is about 7 cfs, based on the low flow in August. During other portions of the year, groundwater discharge is likely higher. Therefore, on an annualized basis, groundwater baseflow discharge to Little Bear Creek is likely higher

Groundwater Recharge (GW) was estimated by the Thornthwaite method to be 8 inches (Golder, 2000). This is equivalent to 5,700 acre-feet per year, or 7.9 cfs annual groundwater recharge. Although there are limitations to the Thornthwaite method for estimating recharge, this is consistent with the estimated groundwater baseflow discharge of 7 cfs.

Estimates of groundwater recharge over the project area were also developed by the USGS as part of the Snohomish County Groundwater Management Program (Thomas et al., 1997). The USGS estimates vary within the project area due to a few factors including: soil type; impervious surface; and precipitation rate. Assuming a precipitation range of 39.9 to 46.8 inches, the USGS estimated 15 inches/yr to 19 inches/yr of groundwater recharge in areas covered by till soils (Figure 5). This is equivalent to 10,693 to 13,545 acre-feet per year, or 14.7 to 18.7 cfs annual groundwater baseflow discharge. These recharge rates are greater than the Thornthwaite Method and the estimated baseflow discharge to Little Bear Creek.

Given the available data and analyses, it is unlikely that average groundwater recharge rates are greater than 15 in/yr, and it is possible that recharge rates are lower.

3.5 Hydrogeologic Cross-Sections

Four hydrogeologic cross-sections were prepared based on available well log data. Figure 6 shows the location of the cross-sections, which are attached as Appendix A. Cross-section C-C' is an extension of a cross-section prepared previously by Golder for the CVWD WHPP (Golder, 2000).

The cross-sections depict the sub-surface configuration of the hydrogeologic units described above, based on our interpretation of the well logs. The cross-sections also depict water-level information, where available.

In general, the cross-sections show a relatively uniform blanket of till throughout the Little Bear Creek sub-basin. Till-like materials are described in virtually every well log. In the areas where the largest increases in medium and low residential zoning density are proposed, there is a consistent presence of till ranging in thickness from 20 to 60 feet. Groundwater levels are generally below the bottom of the till. Thus, there appears to be a good separation between the ground surface and the underlying water-bearing aquifer materials. One anomaly was noted in the description of geologic materials and water-levels in the well logs used on the cross-sections. In the vicinity of Pioneer and Sunset Road (which is within the zone where zoning changes are proposed). A well in that area shows fairly shallow groundwater and relatively thin veneer of gravel and clay.

This well log is consistent with geologic mapping that shows advance outwash (Qva) at the ground surface. However, other wells in the area report till at the ground surface. Further mapping and accurate locations for wells would be necessary to match the geologic mapping with well log information

3.6 Groundwater Flow

The direction of groundwater flow can be determined using water level elevations measured in wells. Water levels are plotted on a map and contours are drawn to show lines of constant elevation. Groundwater flows from higher to lower elevations.

Figure 7 presents groundwater flow in the primary aquifer (Vashon Advance (Qva) Aquifer) based on water level information compiled for approximately 170 wells completed in the Vashon advance outwash. Groundwater generally follows the local topography and moves from high altitude areas toward stream channels and the edges of the plateau. Recharge travels vertically downward to the aquifer through the overlying layers. Mounds of groundwater typically occur under the areas of relatively higher topography with flow radically outward from the center of the mounds.

Two groundwater divides are present in this depiction of flow. One groundwater divide exists along the eastern portion of the Little Bear Creek sub-basin, trending in a northwesterly direction, similar to the orientation of the Snohomish River. Groundwater on the east side of the divide discharges toward the Snohomish River, while groundwater on the west side of the divide discharges toward Little Bear Creek or the Sammamish River.

A second divide appears to be present between the Little Bear Creek and North Creek sub-basins. This divide begins in the vicinity of Thrashers Corner and trends in a southeasterly direction approximately along the topographic divide between the two sub-basins. Groundwater on the east side of the divide discharges toward Little Bear Creek, while groundwater on the west side of the divide discharges toward North Creek and the Sammamish River. The second groundwater divide is generally south of the area where land use changes are proposed under the FEIS Council Map List. However, it is possible that some areas on the western edge of the proposed up zone could flow toward North Creek. Regardless of the discharge locations, the groundwater divide also signifies the presence of a recharge area on the western edge of the Little Bear Creek sub-basin. There are several small areas along the divide (in both the Little Bear Creek and North Creek sub-basins) where higher land use densities are proposed. It is not possible to confirm whether groundwater in these areas is flowing toward Little Bear Creek or North Creek. For the initial FEIS screening, it was assumed that all groundwater effects would occur within the sub-basin in which the land use changes occur. For these small areas south of Thrashers Corner, this may not be the case, and groundwater effects may occur in the North Creek sub-basin.

3.7 Groundwater Quality

Water quality in the area is generally good. Water quality data within the Qva aquifer as a whole was collected by the USGS in 1993. A total of 20 wells completed within or in the vicinity of the Little Bear Creek sub-basin. The water quality in these wells meets all primary drinking water standards. Secondary standards for iron and manganese were exceeded in some wells. Nitrate was detected in all sampled wells analyzed for nitrate (13) at levels ranging between 0.068 to 3.47 mg/L, which meets groundwater quality standards. Based on the 1993 USGS sampling results, no spatial trends or relationships in groundwater quality were discerned within the Cross Valley Aquifer.

3.8 Flowpaths of Concern

The primary concern is the potential to affect the Qva aquifer, which is used for potable supply and also provides groundwater baseflow discharge to Little Bear Creek. Both the current allowable land use and the proposed land use under the FEIS Council Map List have the potential to affect groundwater quantity and quality. Any development in areas where the Qva Advance Outwash is exposed at the ground surface (see Figures 3 and 7) are susceptible to contamination and there could be effects from impervious surfaces on groundwater baseflow to Little Bear Creek.

The FEIS Council Map List, proposes increased medium density zoning in the northwestern quadrant of the basin (see Figures 3 and 7). Based on geologic mapping, Advance Outwash (Qva) is exposed at the ground surface or is relatively shallow over portions of this area. Some well logs in this area report till at the ground surface. Therefore, there is some uncertainty regarding actual conditions in the area proposed for upzoning. The increased zoning density in the north western quadrant of the basin may cause additional impacts to groundwater as follows:

- Increased potential for direct contamination of the Qva aquifer. Geologic maps show Qva at the surface in this area. While there are no larger municipal water systems that would be affected, this could be a concern to local domestic water supplies.

- Increased potential for groundwater recharge reduction. Because portions of the area are mapped as Qva, high groundwater infiltration rates are possible. Impervious surfaces that are not managed to maintain infiltration to groundwater could reduce groundwater recharge.

- Increased potential for groundwater baseflow reduction to Little Bear Creek. Infiltration reaching the Qva in this area appears to flow to the southwest, toward the headwaters of Little Bear Creek. Reduction in recharge may lead to reduction in groundwater baseflow to Little Bear Creek. However, this area is near the boundary with the North Creek sub-basin, and it is possible that some flow from this area may discharge to North Creek.

3.9 Groundwater management issues

Managing effects to groundwater from development in the Little Bear Creek sub-basin, whether from the current allowable land use or the proposed FEIS Council Map List, is guided by four programs:

- Washington State Water Quality Standards (Chapter 173-200 WAC) Implementation Guidance;
- Sole Source Aquifer Designation by Section 1424(e) of the Safe Drinking Water Act of 1974 (Public Law 93-523, 42 U.S.C. 300 et. seq);
- Snohomish County Groundwater Management Program (Chapter WAC 173-100); and,
- Critical Aquifer Recharge Area (CARA) Designations through the Growth Management Act (Chapter 36.70A RCW).

While it appears that the FEIS Council Map List could potentially cause additional impacts to groundwater in the Little Bear Creek sub-basin, use of these guidelines, combined with good engineering practice and environmental analysis, should minimize (and could eliminate) additional impacts from the proposed allowable land use under the FEIS Council Map List. Management issues (in general) will most likely revolve around maintenance of high quality groundwater baseflow discharge to Little Bear Creek.

4.0 CONCLUSION

Development in the Little Bear Creek sub-basin, whether under current allowable land-use or the proposed FEIS Council Map List, has the potential to affect groundwater quality and quantity.

Compared with current allowable land-use, the proposed FEIS Council Map List creates higher medium residential density on an area in the northwestern quadrant of the Little Bear Creek sub-basin, where current geologic mapping indicates that the advance outwash (Qva) is exposed at the ground surface. This could affect groundwater quality and quantity in the Qva aquifer. Therefore, there is a potential for increased effects to groundwater from the FEIS Council Map List proposal.

There is some conflicting evidence regarding the occurrence of advance outwash (Qva) in the area proposed for upzoning. Some well logs in the area report glacial till at the ground surface, rather than advance outwash (Qva). Both the reconnaissance geologic mapping conducted by the USGS and the geologic descriptions in well logs have inherent limitations that cannot be resolved until a site-scale geotechnical investigation is initiated. The potential for some development on the advance outwash, combined with uncertainty regarding site-scale flow paths and geologic conditions suggests that the County should consider one of the following alternatives to managing potential groundwater impacts from the proposed Council FEIS Map List land use (or similar alternatives that identified UGA expansions in this area, e.g. Alternatives 2 and 3):

a. Avoid urban land use designation on the Qva until additional analysis is conducted. This would require ground-truthing in the field the areas that are mapped as Qva and establishing their relationship and proximity to new parcels that would be designated as an urban land use.

b. Provide a provision to phase urban development on the Qva if additional information in the future supports it. This could be accomplished by using an “other” land use designation or by establishing a provision that postpones implementation of the zoning until additional information is available.

c. Provide a provision, perhaps through implementation of the County’s Critical Aquifer Recharge Area (CARA) ordinance, insuring that County staff would have the ability to require site investigations and mitigation requirements for development that negatively impacts groundwater where the additional urban land use designations coincide with areas containing advance outwash (Qva). Mitigation could include clustering, infiltration, and other low impact development measures.

5.0 REFERENCES

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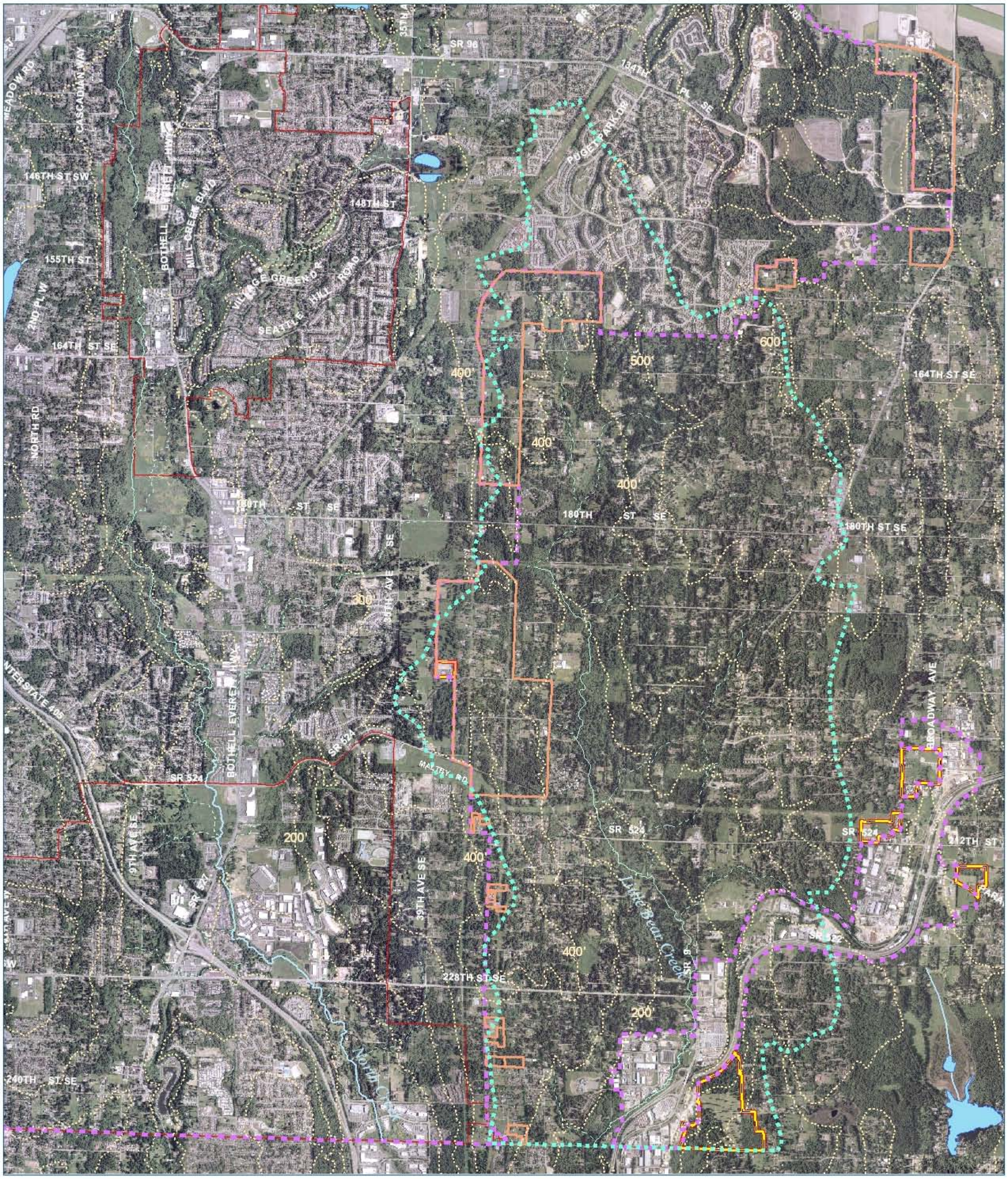
FIGURES



LEGEND

Possible County Council UGA Expansionsto PC Rec.	**Streams**
Proposed PC Rec. UGA Expansions	Type 1
Little Bear Creek Drainage Basin	Type 2
Existing UGA Boundary	Type 3
Incorportated Cities	
Topo -100ft contours	

Source: Snohomish County Department of Planning and Development Services (October 2005)

FIGURE **1**

LITTLE BEAR CREEK DRAINAGE BASIN

JONES & STOKES/SNOHOMISH COUNTY/WA

0331027000fg03.fh11 | Mod: 10/27/05 | EL

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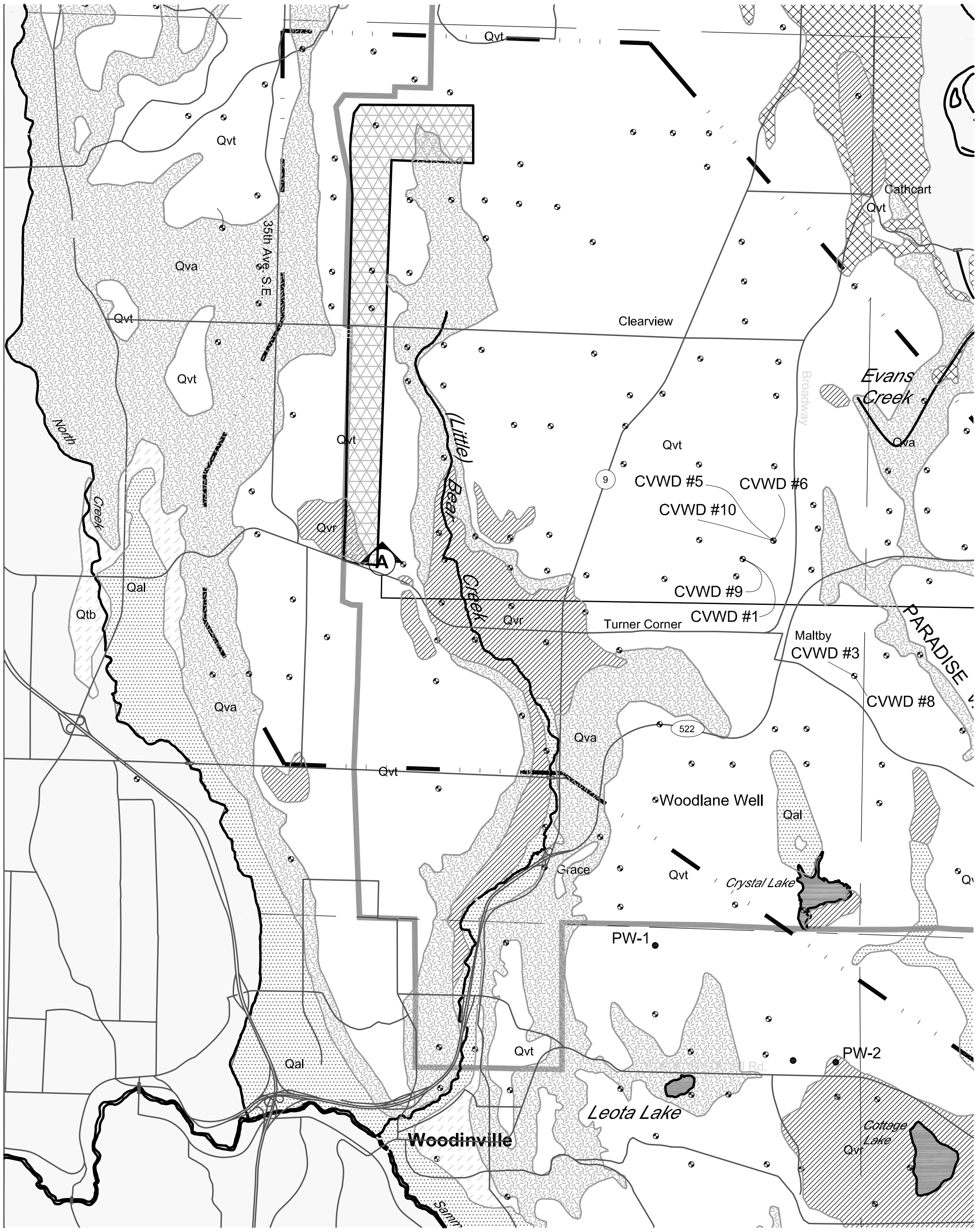

LEGEND:

200	GROUNDWATER ELEVATION CONTOUR
	INFERRED GROUNDWATER FLOW DIRECTION IN THE CROSS VALLEY AQUIFER
	WATER WELL
PW-1	WOODINVILLE WATER DISTRICT WELL LOCATION AND DESIGNATION
CVWD #1	CROSS VALLEY WATER DISTRICT WELL LOCATION AND DESIGNATION
A A	GEOLOGIC CROSS SECTION LOCATION
	CVWD SERVICE AREA BOUNDARY
	SOLE SOURCE AQUIFER BOUNDARY
	INTERPRETED GROUNDWATER DIVIDE

GEOLOGIC UNITS:

- ORGANIC DEPOSITS (Qm)
- ALLUVIUM (Qal)
- RECESSIONAL OUTWASH (Qvr)
- TILL (Qvt)
- ADVANCE OUTWASH (Qva)
- TRANSITIONAL BEDS (Qtb)
- UNDIFFERENTIATED DEPOSITS (Qu)
- BEDROCK (Tb)

OTHER SYMBOLS:

- WATER
- LAND OUTSIDE OF PROJECT AREA
- PROPOSED ZONING

NOTE:
This map was developed from existing maps prepared by the U.S. Geological Survey.

0 6000 1200

SCALE IN FEET

FIGURE 2

SURFICIAL GEOLOGY AND WELLS

J&S/10 YR PLAN & EIS UPDATE/WA

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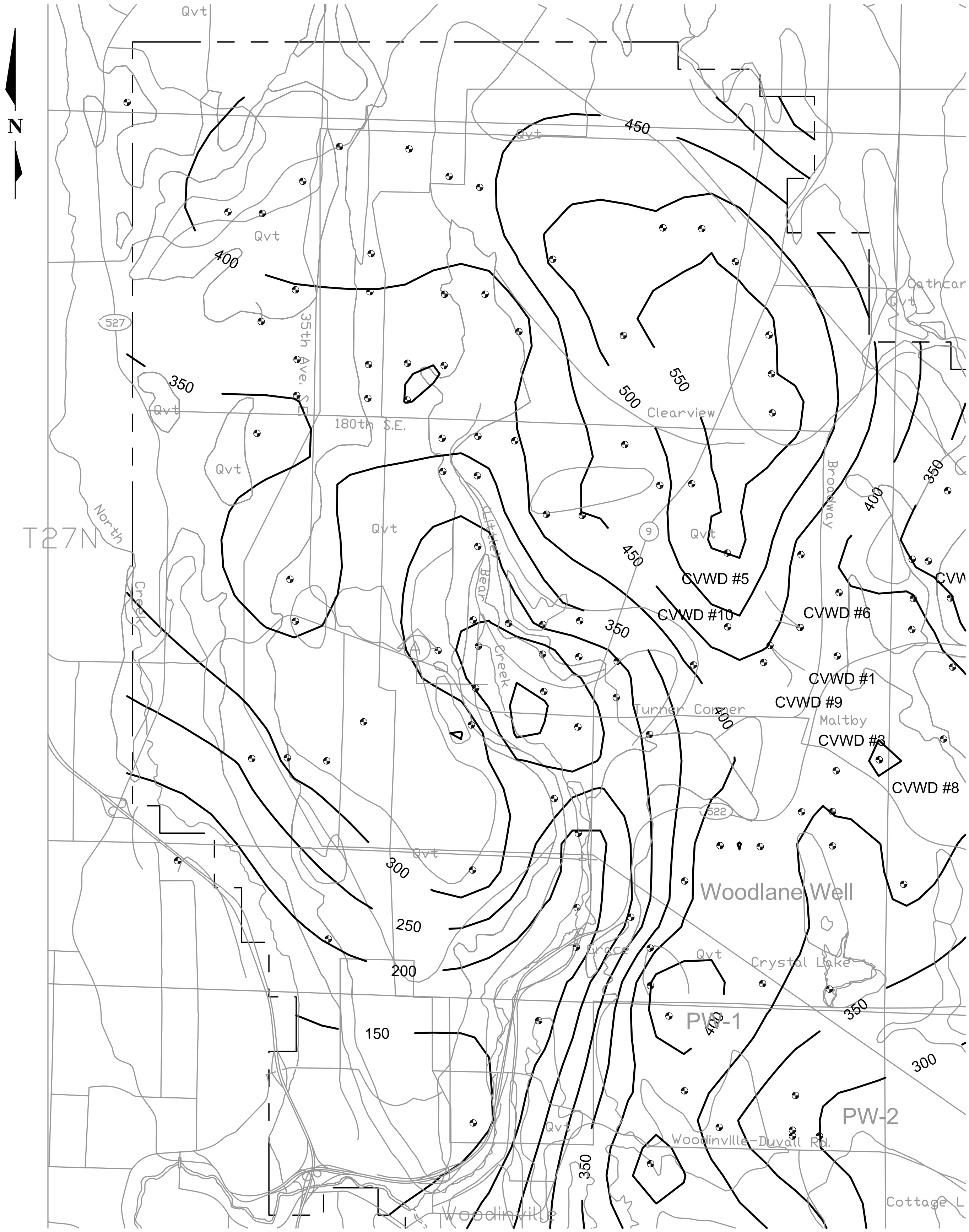


LEGEND:

350 TOP OF ADVANCE OUTWASH.

WELL/DATA POINT

NOTE:
CONTOUR INTERVAL = 50 FT.

0 5000 10000

SCALE IN FEET

FIGURE 3

TOP ELEVATION OF THE VASHON ADVANCE OUTWASH

J&S/10 YR PLAN & EIS UPDATE/WA

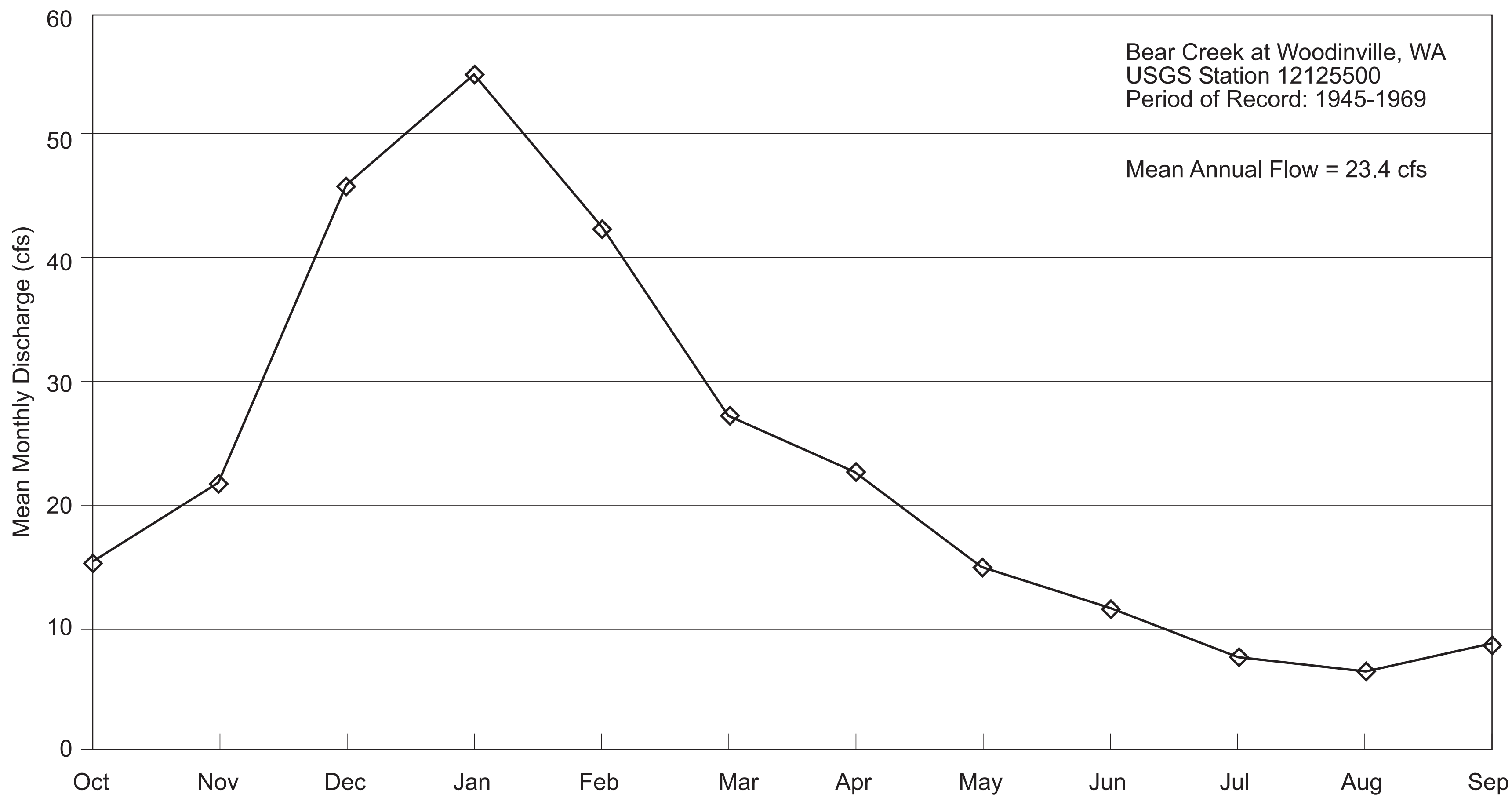
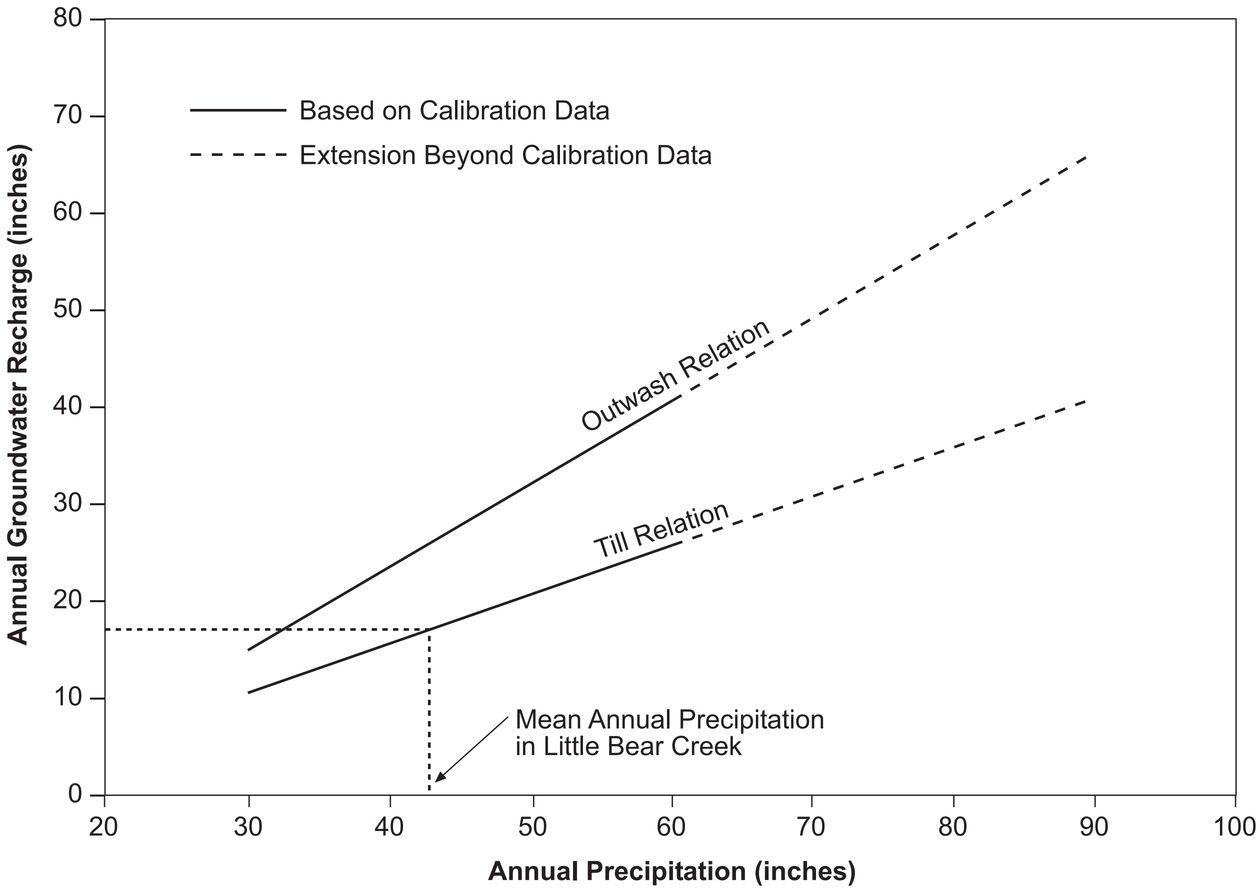


FIGURE **4**

LITTLE BEAR CREEK HYDROGRAPH

JONES & STOKES/SNOHOMISH COUNTY/WA

Golder Associates



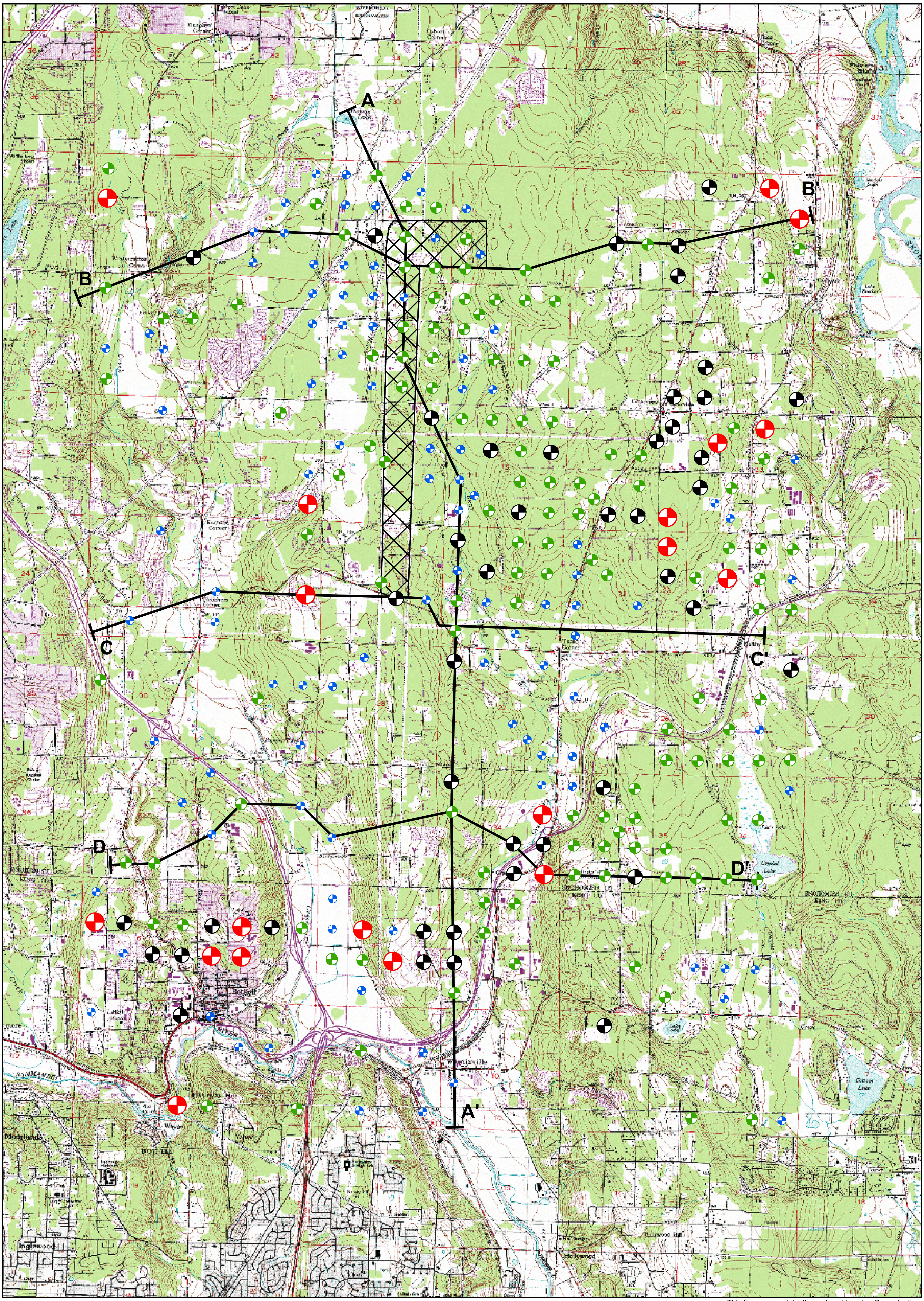
Source

USGS Water Resources Investigations
Report 96-4312, Thomas et al., 1997

FIGURE 5
PRECIPITATION-RECHARGE RELATIONSHIPS FOR WESTERN SNOHOMISH COUNTY, WASHINGTON

JONES & STOKES/SNOHOMISH COUNTY/WA

Golder Associates



LEGEND

Cross Section

Bear Creek Wells

> 100 (Feet)

101 - 200 (Feet)

201 - 300 (Feet)

< 300 (Feet)

Approximate area of proposed increase in medium and low density residential zoning

0 4000

Scale in Feet

DRAFT

Map Projection: Washington State Plane, North Zone, NAD 83, Feet

Source: USGS, WSDOE

N

This figure was originally produced in color. Reproduction in black and white may result in a loss of information.

FIGURE 6

WELL AND CROSS-SECTION LOCATIONS

J AND S/10 YR PLAN AND EIS UPDATE/WA

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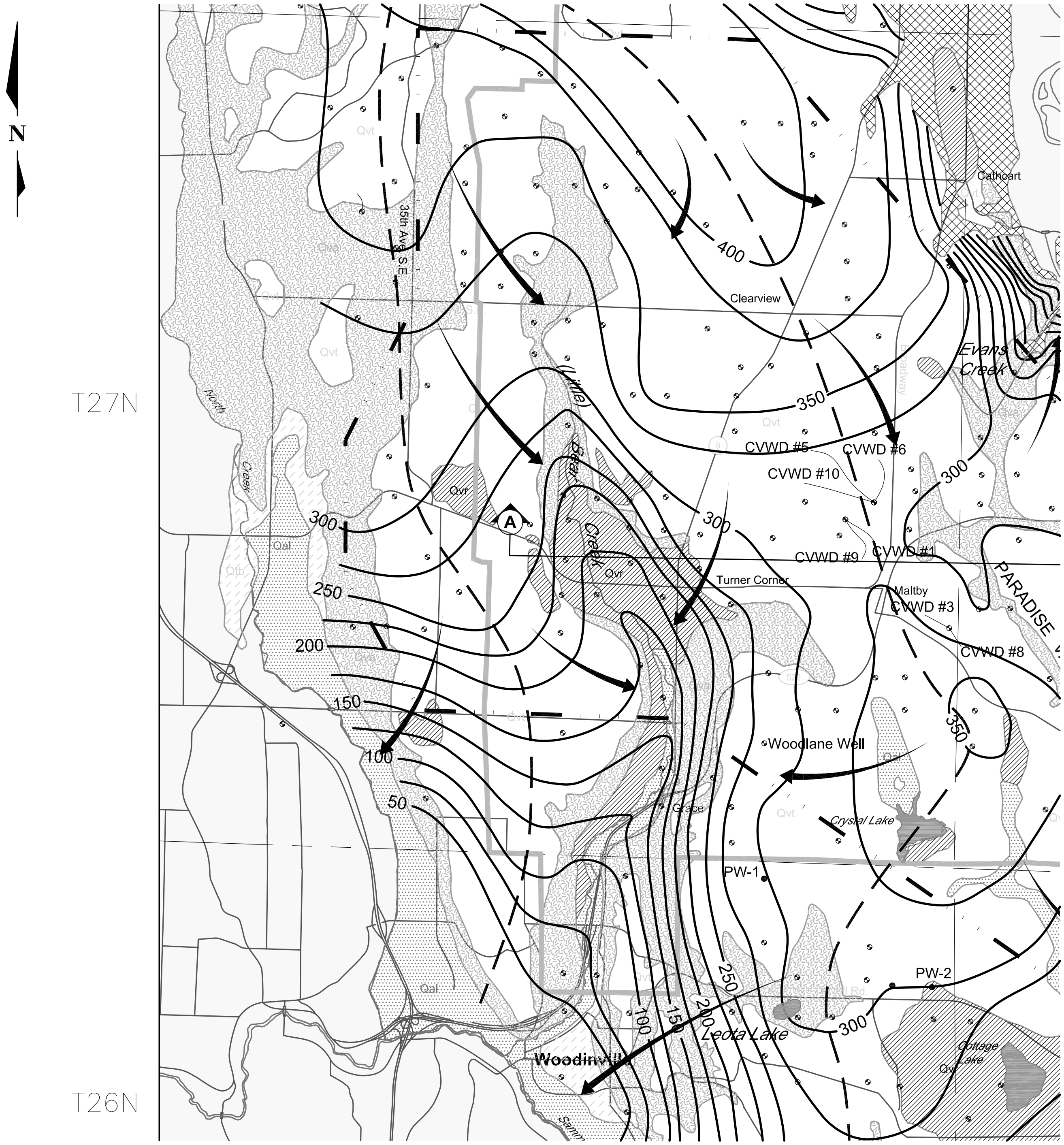

LEGEND:

- 200 — GROUNDWATER ELEVATION CONTOUR
- INFERRED GROUNDWATER FLOW DIRECTION IN THE CROSS VALLEY AQUIFER
- WATER WELL
- PW-1 — WOODINVILLE WATER DISTRICT WELL LOCATION AND DESIGNATION
- CVWD #1 — CROSS VALLEY WATER DISTRICT WELL LOCATION AND DESIGNATION
- A A — GEOLOGIC CROSS SECTION LOCATION
- CVWD SERVICE AREA BOUNDARY
- SOLE SOURCE AQUIFER BOUNDARY
- INTERPRETED GROUNDWATER DIVIDE

GEOLOGIC UNITS:

- ORGANIC DEPOSITS (Qm)
- ALLUVIUM (Qal)
- RECESSIONAL OUTWASH (Qvr)
- TILL (Qvt)
- ADVANCE OUTWASH (Qva)
- TRANSITIONAL BEDS (Qtb)
- UNDIFFERENTIATED DEPOSITS (Qu)
- BEDROCK (Tb)

OTHER SYMBOLS:

- WATER
- LAND OUTSIDE OF PROJECT AREA

NOTE:
This map was developed from existing maps prepared by the U.S. Geological Survey.

0 6000 1200

SCALE IN FEET

FIGURE 7

GROUNDWATER FLOW IN THE CROSS Qva AQUIFER

J&S/10 YR PLAN & EIS UPDATE/WA

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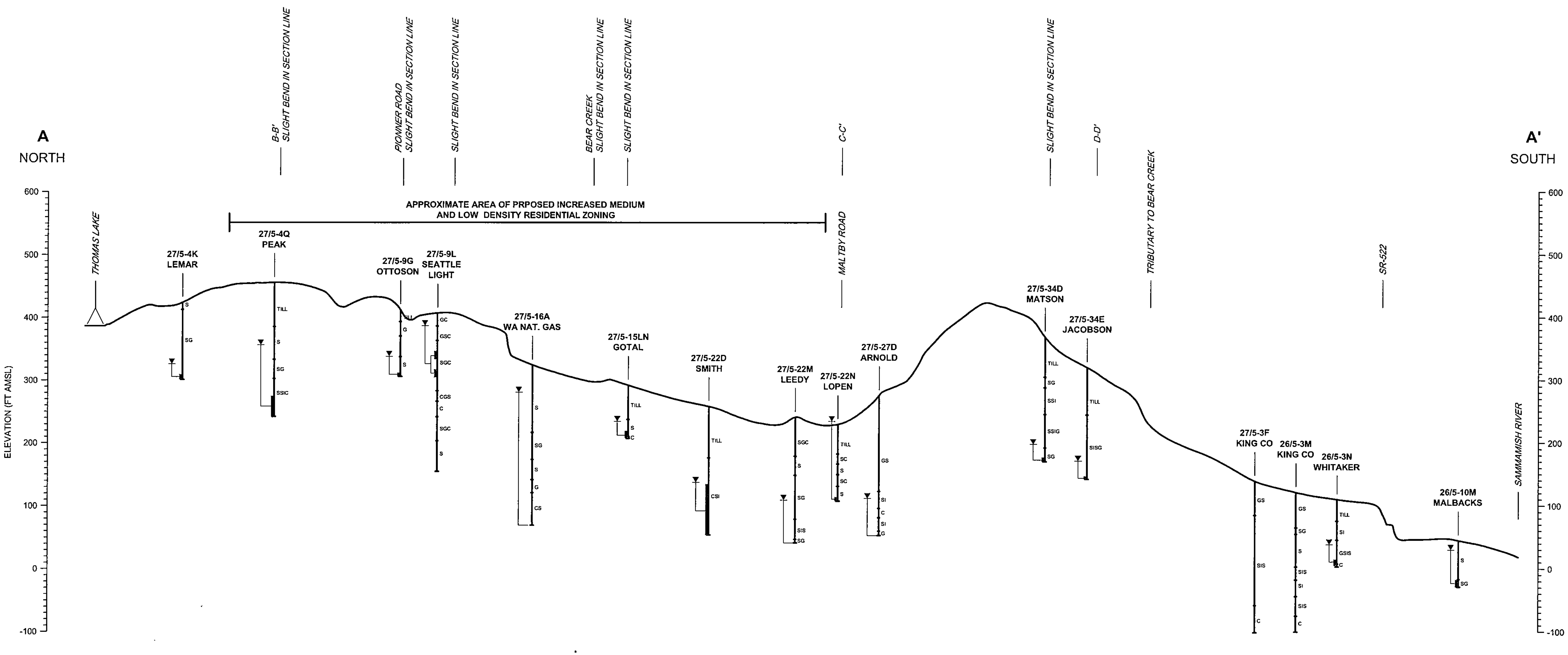
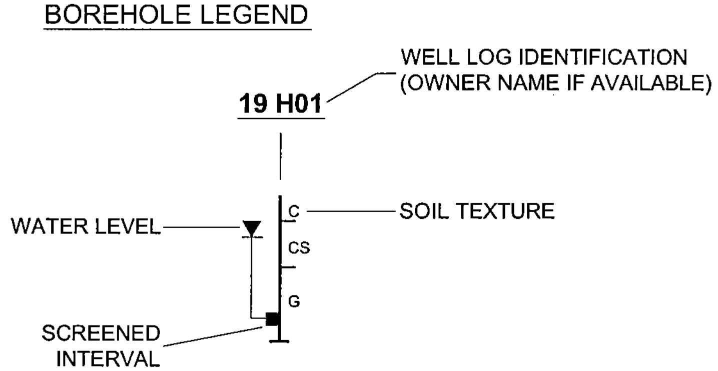
APPENDIX A

HYDROGEOLOGIC CROSS SECTIONS



BOREHOLE LEGEND



NOTE:
WELL LOCATIONS ARE FROM DEPARTMENT OF ECOLOGY'S WELL DATABASE. ACTUAL WELL LOCATIONS HAVE NOT BEEN VERIFIED.

SOIL TEXTURE DESCRIPTIONS

B = BOULDERS
G = GRAVEL
S = SAND
SI = SILT
C = CLAY

TILL = SAND, GRAVEL AND BOULDERS IN A MATRIX OF SILT AND CLAY

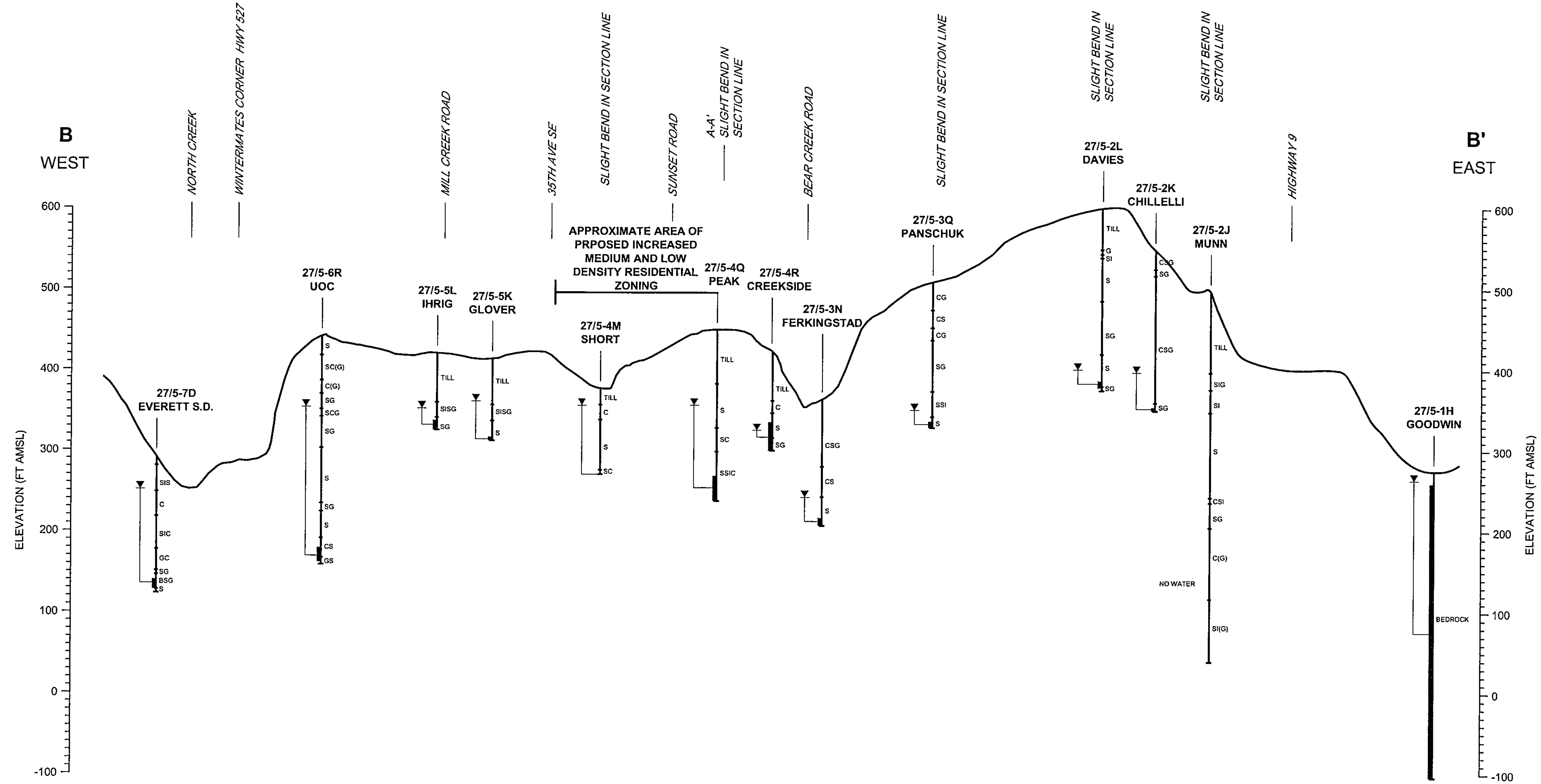
PARENTHESES INDICATES IS PRESENT IN MINOR AMOUNTS

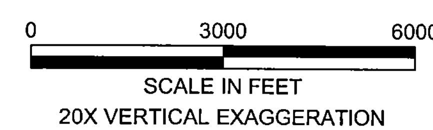
GEOLOGIC UNITS

Qvt: VASHON TILL
Qva: VASHON ADVANCE OUTWASH
Qtb: TRANSITIONAL BEDS

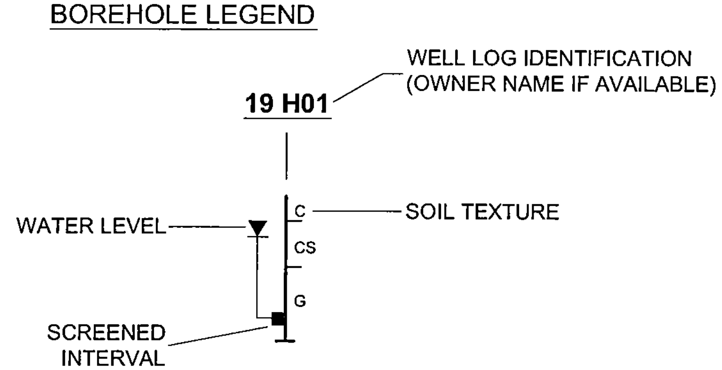
0 3500 7000
SCALE IN FEET
20X VERTICAL EXAGGERATION

FIGURE **A-1**
HYDROGEOLOGIC CROSS-SECTION
J&S/10 YR PLAN & EIS UPDATE/WA





BOREHOLE LEGEND



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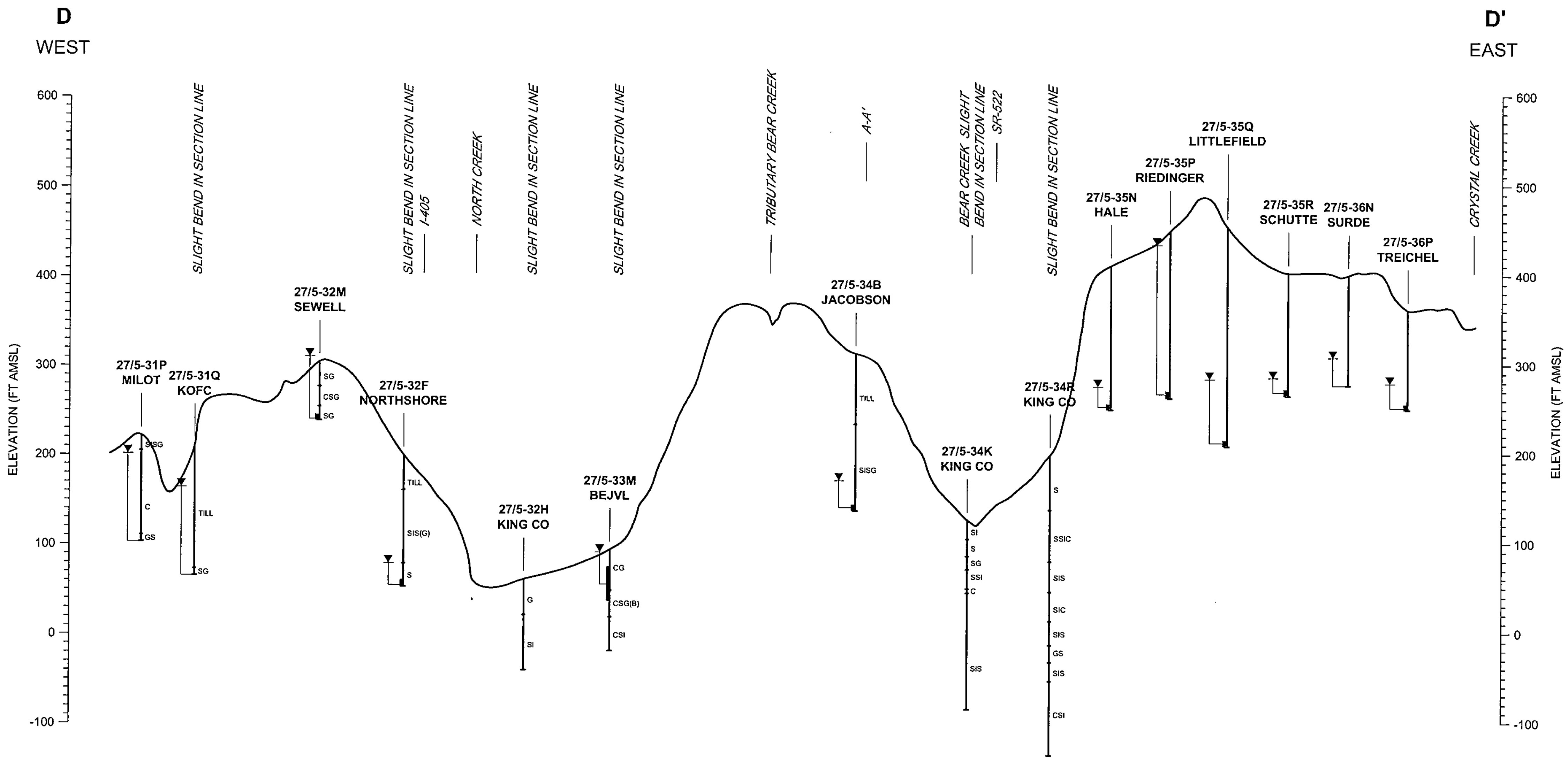
GEOLOGIC UNITS

Qvt: VASHON TILL
Qva: VASHON ADVANCE OUTWASH
Qtb: TRANSITIONAL BEDS

FIGURE **A-2**
HYDROGEOLOGIC CROSS-SECTION
J&S/10 YR PLAN & EIS UPDATE/WA

Golder Associates



BOREHOLE LEGEND

19 H01 — WELL LOG IDENTIFICATION (OWNER NAME IF AVAILABLE)

WATER LEVEL

SOIL TEXTURE

C
CS
G

SCREENED INTERVAL

NOTE:
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SI = SILT

C = CLAY

TILL = SAND, GRAVEL AND BOULDERS IN A MATRIX OF SILT AND CLAY

PARENTHESES INDICATES IS PRESENT IN MINOR AMOUNTS

GEOLOGIC UNITS

Qvt: VASHON TILL

Qva: VASHON ADVANCE OUTWASH

Qtb: TRANSITIONAL BEDS

0 3000 6000

SCALE IN FEET

20X VERTICAL EXAGGERATION

FIGURE **A-3**

HYDROGEOLOGIC CROSS-SECTION

J&S/10 YR PLAN & EIS UPDATE/WA

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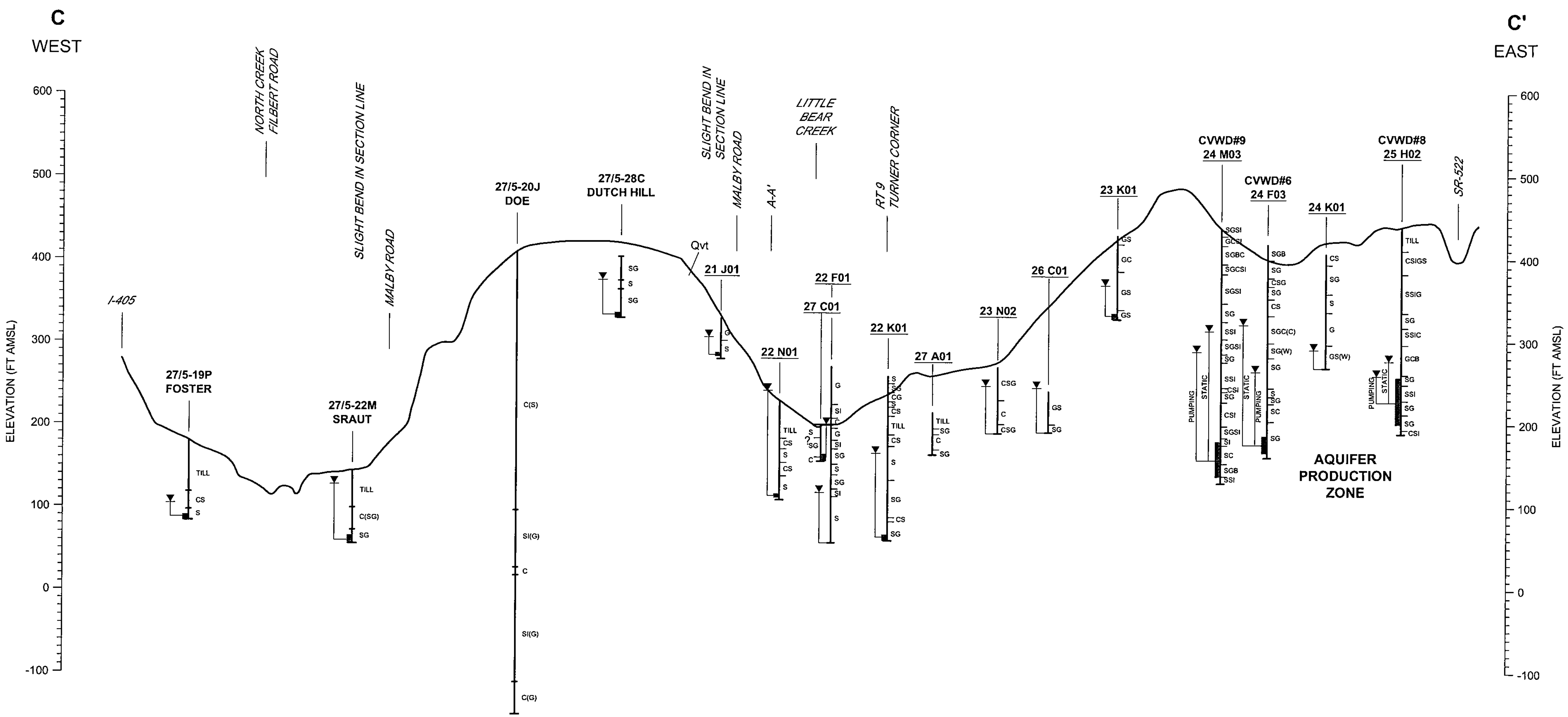
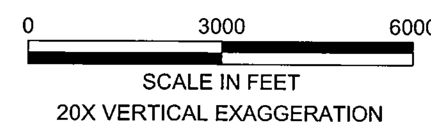
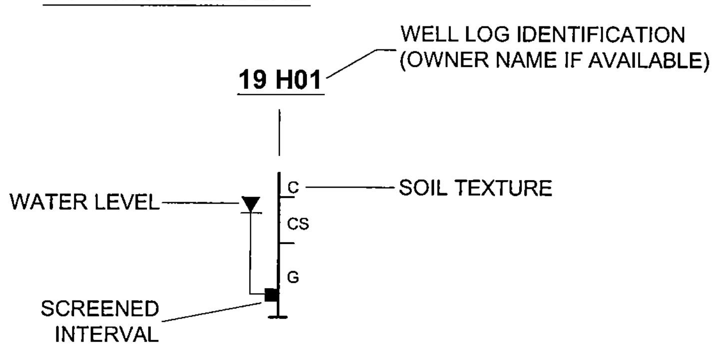




BOREHOLE LEGEND



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TILL = SAND, GRAVEL AND BOULDERS IN A MATRIX OF SILT AND CLAY

PARENTHESES INDICATES IS PRESENT IN MINOR AMOUNTS

GEOLOGIC UNITS

Qvt: VASHON TILL
Qva: VASHON ADVANCE OUTWASH
Qtb: TRANSITIONAL BEDS

FIGURE **A-4**
HYDROGEOLOGIC CROSS-SECTION
J&S/10 YR PLAN & EIS UPDATE/WA

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